DOCUMENT RESUME

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ABSTRACT

In this activity, students investigate the accuracy of sundials and the discrepancy that lies between "real time" and "clock time". The position of the sun is tracked over the course of a relatively short period of time as students make a shadow plot, a horizontal sundial, and a diptych sundial. This activity requires 90-minutes over several weeks for completion. (Author/SOE)

Activity: **Portable Sundial**

GRADE LEVELS: 6-8

SUMMARY:

In this activity students will investigate the accuracy of sundials and the descrepency that lies between "real time" and "clock time". They will track the position of the sun over the course of a relatively short period of time as they make a shadow plot, a horizontal sundial, and a diptych sundial. (The activity may be abridged to include only one or two of the different sundials, instead of all three.)

LEVEL OF DIFFICULTY [1 = Least Difficult: 5 = Most Difficult]

Shadow Plot: 2-minimally difficult

Horizontal Sundial: 3-average

Diptych Sundial: 3-average

TIME REQUIRED

10-90 minutes

- Shadow Plot: 10 minutes for construction; 1 day to several weeks for observation
- Horizontal Sundial: 40 minutes (1 class period for construction; immediately ready for use)
- Diptych Sundial: 40-90 minutes (1-2 class periods for construction; immediately ready for use)

COST

$10-$15 per class

- Shadow Plot: $1.00-$1.50 per sundial

- Horizontal Sundial: $1.50-$2.00 per sundial
- Diptych Sundial: Less than $0.50 per sundial

STANDARDS:

2. Materials, Tools, and Machines:

1.1 Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., weight, strength, hardness and flexibility).

1.2 Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.

1.3 Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sanders, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.

WHAT WILL THE STUDENTS LEARN?

How the sun moves across the sky

The difference between "clock time" and "real time"

How to find geographical north

Terminology such as solstice, equinox, etc.

How to make a sundial and what makes it accurate and what skews the time it tells

BACKGROUND INFORMATION:

VOCABULARY:

TIME: the period during which an action, process, or condition exists or continues; a minute, hour, day, or year as indicated by a clock or calendar

STANDARD TIME: the time established by law or by general usage over a region or country

DAYLIGHT SAVINGS TIME: time usually one hour ahead of standard time

NOON: the middle of the day: 12 o'clock in the daytime; Noon has not always meant "12 o'clock in the daytime". In the ancient Roman way of keeping track of

time, the hours of the day were counted from sunrise to sunset. The ninth hour of the their day (about three p.m. nowadays) was called nona, Latin for "ninth". In the early period of English, the word was borrowed as nOn, also referring to the ninth hour after sunrise. By the 14th century, however, the word came to be used for midday, 12 o'clock, as we use it today.

SUNRISE: the apparent rising of the sun above the horizon; the time at which the sun rises

SUNSET: the apparent sinking of the sun below the horizon; the time at which the sun sets

SUNDIAL: a device to show the time of day by the position of the shadow cast on a marked plate or disk usually by an object with a straight edge

GNOMON: an object (as on a sundial) that by the position or length of its shadow serves to indicate the hour of the day

SOLSTICE: the point in the apparent path of the sun at which the sun is farthest north or south of the equator; the time of the sun's passing a solstice which occurs on June 22 and on December 22

EQUINOX: either of the two times each year about March 21 and September 23 when the sun appears overhead at the equator and day and night are everywhere of equal length

RESOURCES:

Websites/Books dealing with the path of the sun, winter and summer solstice, etc.

http://webexhibits.org/daylightsaving/index.html

http://www-istp.gsfc.nasa.gov/stargaze/Secliptc.htm

The path of the sun, seasons and solstices.

http://library.scar.utoronto.ca/ClassicsC42/Gomes/wat.html

History of sundials sorted by civilizations

http://www.hps.cam.ac.uk/starry/sundials.html

History of Sundials

http://www.hps.cam.ac.uk/starry/sundials.html

History of sundial with good pictures

http://www.math.nus.edu.sg/aslaksen/projects/ll-abstract.pdf

Mathematical elements behind sundials. A bit advanced for students but good for teachers

**Humans feel it necessary to mark the passage of time. And everyone has noticed shadows changing throughout the day. Someone unknown in the past found out that if the shadow was cast by a sloping object pointing to the celestial pole, it would cast a consistent shadow which would be in the same place at the same time every day. Though it has been suggested that this may have been 2000 years ago, it is more likely that it would have been around 500 years ago; before the development of clocks, it would have been difficult to determine what "the same time each day" meant.

Practically everybody knows what a sundial is. Most people have a residual idea that, if they had to, they could make one. But most people's practical knowledge of sundials is confined to having seen some standard brass horizontal dials on plinths in gardens.

And there is a widespread--though totally wrong--general impression that sundials are not very good at telling the time. The poor reputation of sundials is ill-deserved, and has arisen mostly because we have all accepted "clock time" as an absolute standard, without devoting any thought to the nature of the time it is measuring.

Sundials measure time as it is. Noon is when the sun is highest in the sky (when it crosses the meridian). Watches measure time as we would like it to be, with noon tomorrow exactly 24 hours, 0 minutes, and 0 seconds away from noon today. But noon on December 26th is actually 24 hours, 0 minutes, and 29 seconds away from noon on Christmas Day. And noon on September 15th is only 23 hours, 59 minutes, and 39 seconds away from noon on the following day.

In the winter the days are short and the sun is low in the sky. Each day after the winter solstice, which occurs on December 21st, the sun's path becomes a little

higher in the southern sky. The sun also begins to rise closer to the east and set closer to the west until we reach the day when it rises exactly east and sets exactly west. This day is called the equinox. In the spring we have the Spring Equinox on March 21st. There is also a Fall Equinox on September 21st.

The sun is at its lowest path in the sky on the Winter Solstice. After that day the sun follows a higher and higher path through the sky each day until it is in the sky for exactly 12 hours. Every place on earth experiences a 12-hour day twice a year on the Spring and Fall Equinox.

On the Summer Solstice the sun is at its highest path through the sky and the day is the longest. Because the day is so long the sun does not rise exactly in the east, but rises to the north of east and sets to the north of west allowing it to be in the sky for a longer period of time.

After the Summer Solstice the sun follows a lower and lower path through the sky each day until it reaches the point where it is in the sky for exactly 12 hours again. This is the Fall Equinox. Just like the Spring Equinox, the sun will rise exactly east and set exactly west on this day and everyone in the world will experience a 12-hour day.

After the Fall Equinox the sun will continue to follow a lower and lower path through the sky and the days will grow shorter and shorter until it reaches its lowest path and then we are back at the Winter Solstice where we started.

MATERIALS: *(required to make one sundial)*

Shadow Plot:

1-piece of large white paper

1-pencil width wooden dowel (or similar) 12" to 15" long

1-ball of clay

2-12" piece of duct tape, cut into 8-3" strips

1-permanent magic marker

1-timer

Horizontal Sundial:

1-small wooden disk

1-3/4"-1" nail

1-pencil

1-pen

1-pair of scissors

1-index card

1-hammer

1-protractor

1-sheet of paper

string (optional)

wood glue

Diptych Sundial:

1-template for diptych assembly (see link)

1-piece of heavy paper

glue

string, preferably elastic

PREPARATION:

Shadow Plot:

Obtain materials

Cut wooden dowel to 12" to 15" long if necessary

Locate geographic north (directions included)

Horizontal Sundial:

Obtain materials

Locate your latitude (www.topozone.com)

Locate geographic north (see 'Directions')

(optional) If you want to make your sundial into a necklace or keychain, drill a hole into the wooden disk to pass the string through

See the directions--if doing this activity with a large group of young children it is often best to prepare the nails in the wooden disks as well (steps 1-2 in 'Directions')

Diptych Sundial:

Obtain materials

Print out the Diptych Template (see link)

Locate your latitude (www.topozone.com)

Locate geographic north (see 'Directions')

DIRECTIONS:

There are infinite possibilities for the number of topics this activity can fit with. One suggestion is to discuss/talk with the students about the way time is measured, the history of clocks and the way that we tell time.

Construction & Testing:

PART I. FINDING GEOGRAPHIC NORTH TO POSITION YOUR SUNDIAL*:

The sundial must be orientated with the gnomon pointing north/south and, of course, the dial must be located where a shadow will be cast by the gnomon most of the day. Use one of these methods to find geographic north for your latitude.

METHOD I: (The Purist's Method)

To determine the orientation without reference to other mechanical devices, North can be found by observing Polaris, the North Star, at night. In orientating the sundial, the gnomon is actually being pointed to the North Celestial Pole which is

within 1-degree of the North Star. Thus, if you can find Polaris at the end of the Little Dipper, line up your dial by pointing the gnomon towards Polaris. You might want to record the orientation for you dial for future reference. Those in southern latitudes will not be able to use this method.

METHOD II: (The Practical Method)

A magnetic compass may be used to determine the north/south line, but, because of the difference between magnetic north and true north, the dial reading could be off by an hour or more depending on the local difference between magnetic and true north.

METHOD III: (The Lazy Method)

To a first approximation, the orientation can be found by finding the orientation at any time from a clock or watch and orientating the dial so the shadow shows the correct time. However, if left in this position, there could be an error of up to 30 minutes over the year as a result of what is known as the "equation of time". Because of the Earth's orbital motion around the sun, the solar day (approximately 24 hours) is not exactly the same length from day to day varying by up to +/- 16 minutes a day.

PART II. BUILDING THE SUNDIAL

A. SHADOW PLOT*

CONSTRUCTION: (see the Worksheet for images if need assistance)

A shadow plot can also help you obtain a feel for how the sun's path changes across the sky from day to day. To see this effect it is best to work on the shadow plot for several weeks.

1. It is best to set up your shadow plot in the morning, around 9:00 a.m.
2. Find a flat location, clear from shadows all day long.
3. Push a ball of clay into the ground.
4. Insert the wooden dowel into the ball of clay, so that it stands vertically.

Use four of the strips of duct tape to cover the clay to keep it from melting in the sun and to help secure the dowel. The dowel will need to stand in this exact location for the length of the activity (from one day to several weeks), so make sure it is perfectly vertical and very secure.

5. Once the dowel is in place, look for its shadow. Lie your piece of paper down on the north side of the dowel with the long edge up against the base of the dowel support. (If you did not find geographic north following the directions above, you can determine which direction is north since you know the sun is in the east and the dowel shadow is facing west.)
6. Use the remaining four strips of duct tape to secure the corners of the paper. Make sure to keep the middle of the paper clear as this is where you will be making your plot.
7. You are now ready to start making your measurements. The shadow from the dowel should be on the piece of paper. If it is not wait about an hour and return once the shadow is cast onto the paper. When you have the shadow on the paper, make a mark at the very end of the shadow.
8. Return to the plot about once every 30 minutes and make a mark at the end of the shadow each time. It is helpful to use a timer. If you start your plot at 9:00 a.m. you should have enough markings by 3:00 p.m.

USING YOUR SHADOW PLOT:

9. After one day of shadow measurements you are ready to draw the north-south line. On your completed shadow plot draw a smooth curve through all of the marks that you have made, without moving the paper. The more often you have taken your measurements, the easier it will be to draw this curve accurately.
10. Once you have drawn a smooth curve through the markings, find the shortest distance between the dowel base and this curve. Draw a line from the dowel base to this point. This line you have just drawn is called a north-south line. It is the line along which the sun will cast a shadow at local noon. (Your local noon may not be exactly when the clock says noon

depending on where you are in your time zone.) This north-south line points exactly north and south. A line drawn perpendicular to this line will point East and West. You will need to know the exact direction of North to use your horizontal sundial.

B. HORIZONTAL SUNDIAL**

CONSTRUCTION: (see the Worksheet for images if need assistance)

To align our gnomon we must position it such that it makes an angle equal to the latitude angle where it will be used with the horizontal face of the sundial. The easiest way to get the nail into the wooden disk at this angle is to do the following:

1. Hammer the nail straight into the center of the wooden disk making sure not to hammer the nail through the back side of the disk.
2. Hammer the nail from side so that it begins to bend over. Continue to bend the nail over until it is at the same angle as your latitude. If the nail becomes loose, a little wood glue at the base should secure it.
3. To begin construction of the hour line template, draw a horizontal line on the piece of white paper using a pencil.
4. Align the protractor on the horizontal line and make a pencil tick at the 90-degree mark.
5. Draw a vertical line from the tick mark down to the horizontal line. You have just created the noon and six o'clock lines!
6. Use a protractor and make a pencil tick at the following angles FROM THE VERTICAL NOON LINE (on both the left and right hand sides of the vertical line): 10.7, 22.2, 35.3, 50.8, 69.2, and 90. These coincide with 1, 2, 3, 4, 5, and 6 hours from Noon respectively.
7. Use the straight edge of the protractor and connect each tick mark to the intersection of the horizontal and vertical lines.
8. Once you have a hard copy of the image, place the wooden disk on top of the paper such that the center of the disk, where the nail hole is, is directly over the intersection of the horizontal and vertical lines. The horizontal line,

marked with a six on each side, should run underneath your disk exactly across the center.

9. Without shifting the wooden disk, rotate it until the head of the nail is pointing up the 12 o'clock line.

10. Holding the wooden disk very still, make 13 pencil marks on the top face of the wood, each mark inline with the appropriate hour line. Because the face of the sundial is so small it is best to only include a few of the hour numbers.

11. (optional) If you desire to make your sundial into a necklace or keychain, thread the hole with some string to the desired length and tie off.

USING YOUR HORIZONTAL SUNDIAL:

12. Take the sundial outside on a sunny day and hold perfectly horizontal. Make sure to point the head of the gnomon (nail) due north. The shadow cast by the gnomon should fall on the appropriate hour line. This type of sundial is not 100% accurate, but it is close and you should be able to tell the time within 15 minutes. (NOTE: Daylight savings time means you will need to adjust your sundial to agree with local "clock" time.)

C. DIPTYCH SUNDIAL*

CONSTRUCTION: (see the Worksheet for images if need assistance)

The folding sundial you are about to make is called a diptych sundial. Such dials have been made for four or five centuries and were traditionally made of ivory or boxwood. The diptych dial provided here was designed by Dr. Allan Mills, Astronomy Group, Leicester University, UK. The scanned images and text have been prepared by Dr. Randall Brooks, National Museum of Science and Technology, Ottawa, Canada.

1. Obtain the diptych template from your teacher.
2. Paste onto a piece of heavy paper.
3. Obtain the latitude of your location (teacher may provide).

4. On the base of the dial, mark the latitude angle on both scales, drawing lines through each of the X symbols at the top. Cut the flaps off along these lines.
5. Note the dashed lines; two of these are marked "score on back, fold forward" and two marked "score on front, fold down". After scoring, make the necessary folds in the direction indicated.
6. Along the line with "Noon" written above, fold the upper section forward so that the two panels make a right angle.
7. To finish the dial, attach a string (preferably elastic) through holes at the top and bottom at the points where all the hour lines converge so that the string is taught when the dial is folded. This string is the gnomon and casts a shadow to indicate the time.

INVESTIGATING QUESTIONS:

How does the sun appear to move across the sky?

Does the sun change its path through the sky from month to month?

Why is it important for us to have an instrument to mark time?

Why is "true north" important for the accuracy of a sundial?

What is the difference between "real time" and "clock time"?

REFERENCES:

*Sundials on the internet: www.sundials.co.uk

**http://solarphysics.montana.edu (Yohkoh Public Outreach Project, The Solar Classroom)

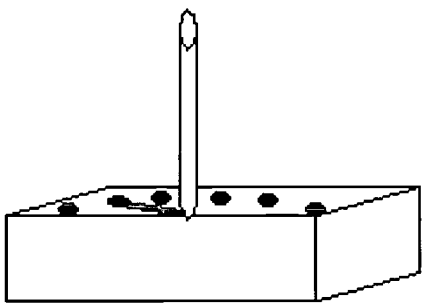
To find your latitude and longitude: www.topozone.com

*This material comes from the projects page of Sundials on Internet at www.sundials.co.uk, a leading information site on all aspects of sundials.

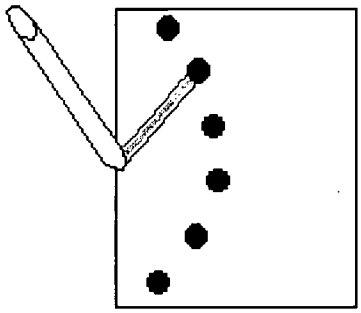
Rubric for Performance Assessment						
Activity Title:	Portable Sundial		Grade Level: 6-8			
	1	2	3	4		
Criteria	Beginning	Developing	Proficient	Advanced	Weight (X factor)	Subtotal
Construction of Instrument	Little time spent; carelessly completed, no details, unsafe tool useage	Some time spent; parts missing; few details; some evidence of expected work.	Enough time spent; carefully finished; lots of details; more work than expected	Extra time spent; carefully finishad; lots of details; more work than expected		
Cooperation	No group work.	Little contribution to group work.	Contributes as expected to group work	Group Leader		
Data Collection	No data collected	Incomplete data; careless write up	Data is easy to read and understand; regular readings recorded	Draws conclusions from data; neat and carefully designed.		
					Total:	
Teacher Comments:						

IMAGES OF SHADOW PLOT CONSTRUCTION

Set-Up:

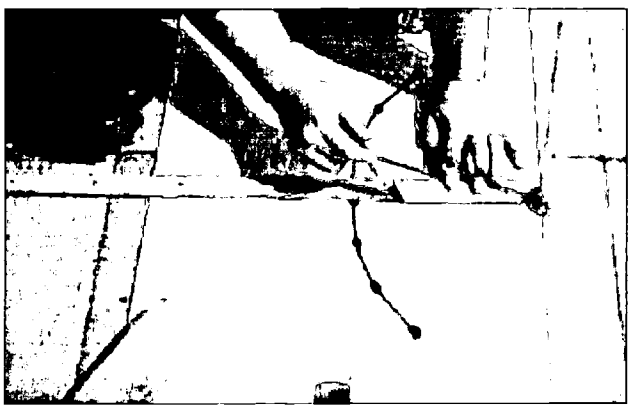


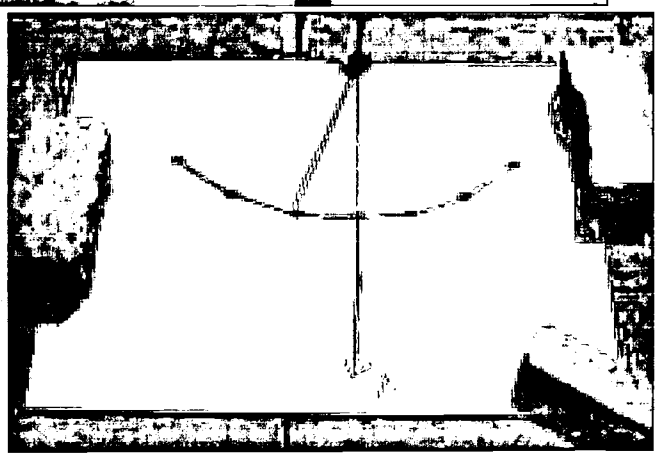
SIDE VIEW



TOP VIEW

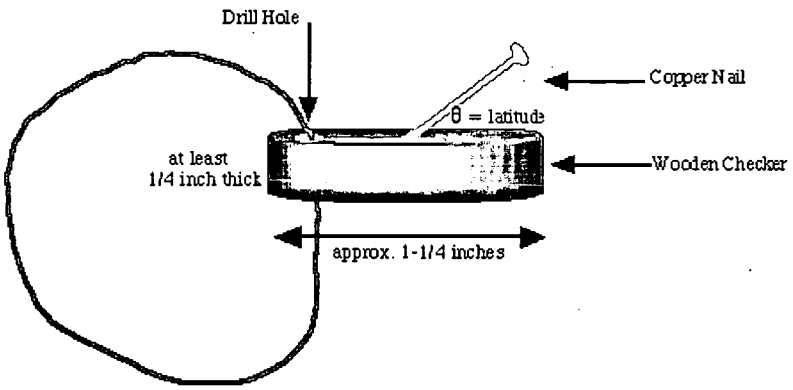
Drawing the North-South line:



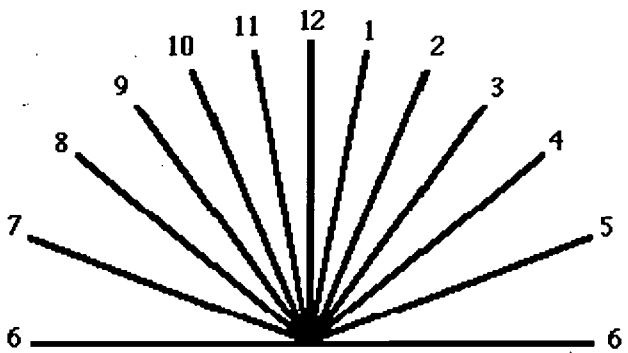


IMAGES OF HORIZONTAL SUNDIAL CONSTRUCTION

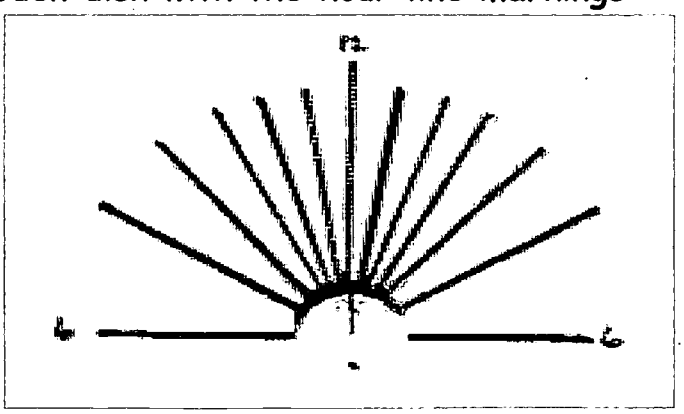
Set-Up:

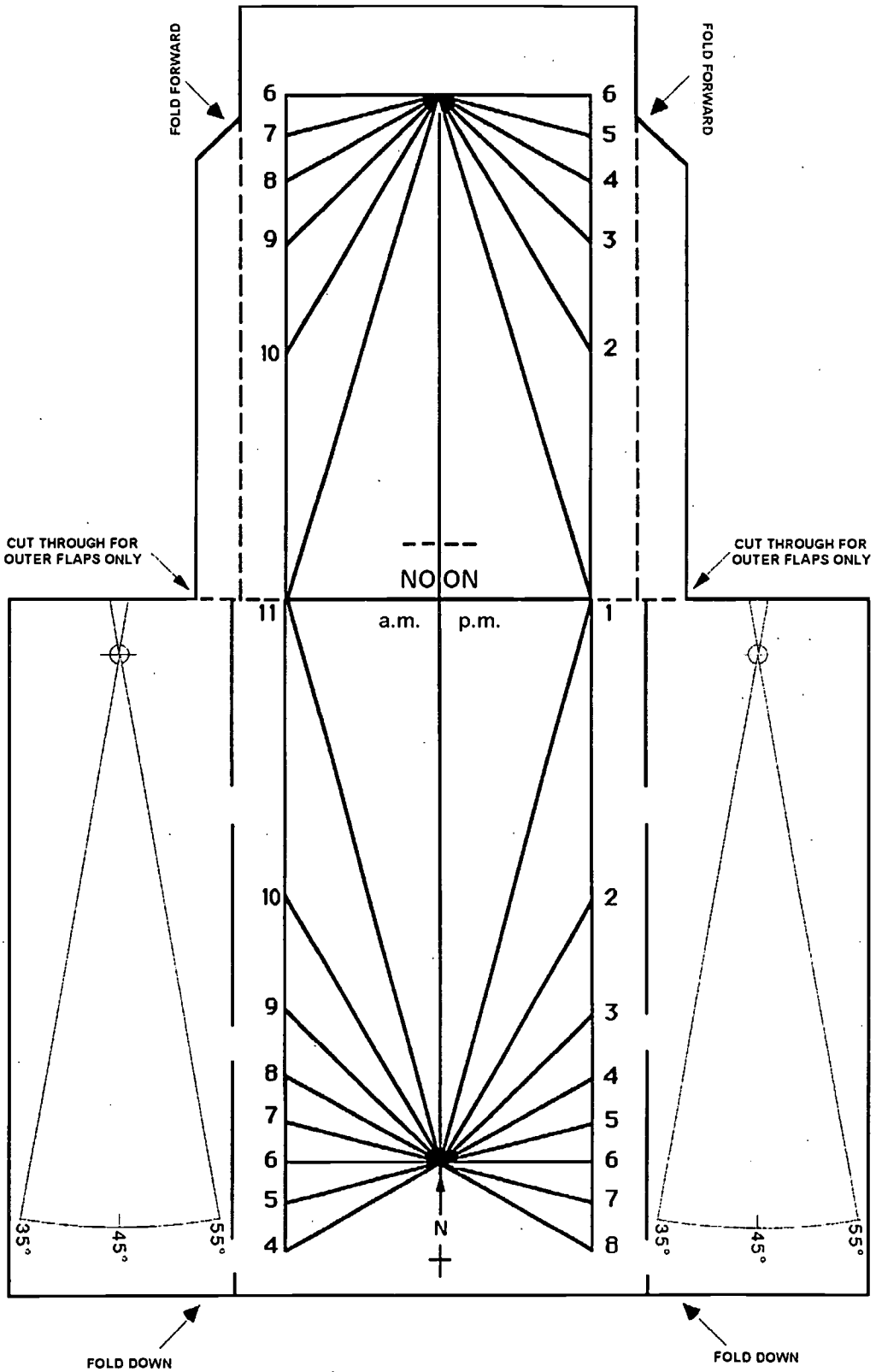


Hour Line Markings for 45° Latitude:



Aligning the wooden disk with the hour line markings:





PreK-12
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Activity Evaluation Form
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Activity Name: _____

Grade Level the Activity was implemented at:_____

Was this Activity effective at this grade level (if so, why, and if not, why not)?

What were the Activity's strong points?

What were its weak points?

Was the suggested Time Required sufficient (if not, which aspects of the Activity took shorter or longer than expected)?

Was the supposed Cost accurate (if not, what were some factors that contributed to either lower or higher costs)?

Do you think that the Activity sufficiently represented the listed MA Framework Standards (if not, do you have suggestions that might improve the Activity's relevance)?

Was the suggested Preparation sufficient in raising the students' initial familiarity with the Activity's topic (if not, do you have suggestions of steps that might be added here)?

If there were any attached Rubrics or Worksheets, were they effective (if not, do you have suggestions for their improvement)?

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I. DOCUMENT IDENTIFICATION:

Title: PreK-12 Engineering Activities

1) Touch and Discover, Grades PreK-2
http://www.prek-12engineering.org/data/d2/Touchdiscover.pdf

2) Invent a Backscratcher from Everyday Materials, Grades PreK-2
http://www.prek-12engineering.org/data/d28/Backscratcher.pdf

3) Compare Human-Made Objects with Natural Objects, Grades PreK-5
http://www.prek-12engineering.org/data/d34/HumanvsNatural.pdf

4) Do Different Colors Absorb Heat Better?, Grades PreK-2
http://www.prek-12engineering.org/data/d37/Absorbheat.pdf

5) Which Roof is Tops?, Grades PreK-2
http://www.prek-12engineering.org/data/d44/RoofTops.pdf

6) Make Your Own Recycled Paper, Grades PreK-2
http://www.prek-12engineering.org/data/d56/Recycle.pdf

7) Build an Approximate Scale Model of an Object Using LEGOs, Grades 3-5
http://www.prek-12engineering.org/data/d3/LegoScaleModel.pdf

8) Design Weather Instruments using Lego Sensors, Grades 3-5
http://www.prek-12engineering.org/data/d4/LegoWeather.pdf

9) Space Shelter, Grades 3-5
http://www.prek-12engineering.org/data/d5/SpaceShelter.pdf

10) Build a Bird House, Grades 3-5
http://www.prek-12engineering.org/data/d6/BirdHouse.pdf

11) Ball Bounce Experiment, Grades 3-5
http://www.prek-12engineering.org/data/d6/BallBounce.pdf

12) Make an Alarm!, Grades 3-5
http://www.prek-12engineering.org/data/d11/MakeAlarm.pdf

13) Design Packing to Safely Mail Raw Spaghetti, Grades 3-5
http://www.prek-12engineering.org/data/d17/MailSpaghetti.pdf

14) Disassemble a Click Pen, Grades 3-5
http://www.prek-12engineering.org/data/d33/clickPen.pdf

15) Construct And Test Roofs for Different Climates, Grades 3-5
http://www.prek-12engineering.org/data/d35/ClimateRoof.pdf

16) Compare Fabric Materials, Grades 3-5
http://www.prek-12engineering.org/data/d36/Fabric.pdf

17) A House is a House for Me, Grades 3-5
http://www.prek-12engineering.org/data/d52/House.pdf

18) Water Filtration, Grades 3-5
http://www.prek-12engineering.org/data/d53/Water Filtration.pdf

19) What is the Best Insulator: Air, Styrofoam, Foil, or Cotton?, Grades 3-5
http://www.prek-12engineering.org/data/d54/BestInsulator.pdf

20) Design a Recycling Game!, Grades 3-5
http://www.prek-12engineering.org/data/d55/Recycling.pdf

21) Tower Investigation and the Egg, Grades 6-8
http://www.prek-12engineering.org/data/d7/TowerEgg.pdf

22) Wimpy Radar Antenna!, Grades 6-8
http://www.prek-12engineering.org/data/d10/WimpyAntenna.pdf

23) Portable Sundial, Grades 6-8
http://www.prek-12engineering.org/data/d30/PortableSundial.pdf

24) An Introduction To Loads Acting on Structures, Grades 6-8
http://www.prek-12engineering.org/data/d31/IntroLoads.pdf

25) Design Your Own Rube Goldberg Machine, Grades 6-8
http://www.prek-12engineering.org/data/d32/RubeGoldberg.pdf

26) Building Tetrahedral Kites, Grades 6-8
http://www.prek-12engineering.org/data/d38/tetrakites.pdf

27) Do as the Romans: Construct an Aqueduct!, Grades 6-8
http://www.prek-12engineering.org/data/d39/Aqueduct.pdf

28) Build an Earthquake City!!, Grades 6-8
http://www.prek-12engineering.org/data/d40/EarthquakeCity.pdf

29) Design a Parachute, Grades 6-8
http://www.prek-12engineering.org/data/d41/Parachute.pdf

30) The Squeeze is On, Grades 6-8
http://www.prek-12engineering.org/data/d42/Squeeze.pdf

31) Stop The Stretching, Grades 6-8
http://www.prek-12engineering.org/data/d43/StopStretching.pdf

32) Speaker Project, Grades 9-10
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Author(s): Erik Rushton, Emily Ryan, Charles Swift

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